US005590208A

United States Patent [19]

Koyano et al.

[11] **Patent Number: 5,590,208**

[45] **Date of Patent: Dec. 31, 1996**

[54] **SPEAKER SYSTEM**

[75] Inventors: **Shinji Koyano; Koushirou Kogure; Takashi Ohyaba; Makoto Sakakibara; Katsutoki Hanayama**, all of Saitama-ken, Japan

[73] Assignee: **Pioneer Electronic Corporation**, Tokyo, Japan

[21] Appl. No.: **419,902**

[22] Filed: **Apr. 11, 1995**

[30] **Foreign Application Priority Data**

Apr. 18, 1994 [JP] Japan 6-079057

[51] **Int. Cl.**[6] **H04R 25/00**

[52] **U.S. Cl.** **381/154**; 381/159; 181/156

[58] **Field of Search** 381/158, 159, 381/160, 154, 188, 205; 181/155, 156, 199

[56] **References Cited**

U.S. PATENT DOCUMENTS

5,197,103 3/1993 Hayakawa 381/159

5,414,230 5/1995 Nienwendijk et al. 381/71

FOREIGN PATENT DOCUMENTS

4-301998 10/1992 Japan 381/159

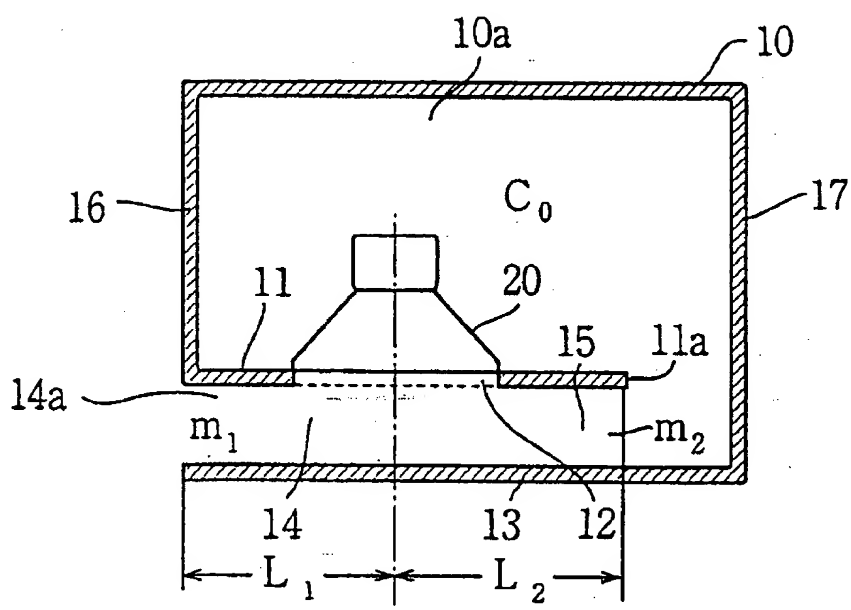
Primary Examiner—Sinh Tran

Attorney, Agent, or Firm—Nikaido, Marmelstein, Murray & Oram LLP

[57] **ABSTRACT**

A duct is provided in a cabinet for radiating sound pressure emitted from a speaker unit. The duct comprises a first duct and a second duct. The first duct extends in a direction perpendicular to a radiating direction of the sound pressure radiated from a front side of the speaker unit. The second duct is connected to an end of the first duct. An inner end of of the second duct is communicated with the cabinet. The speaker unit is disposed at a connection of the first and second ducts.

6 Claims, 12 Drawing Sheets



01/24/2004, EAST Version: 1.4.1

FIG.1 a

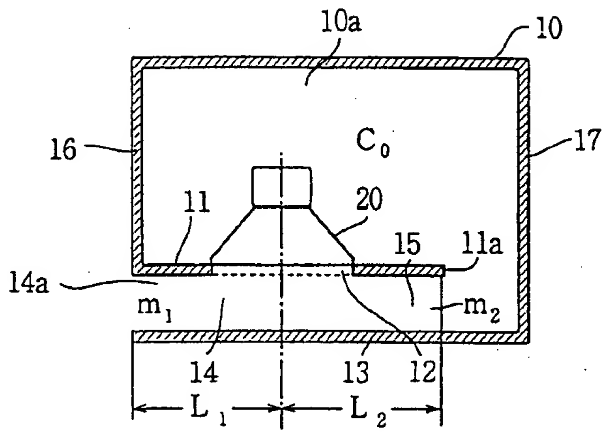


FIG.1 b

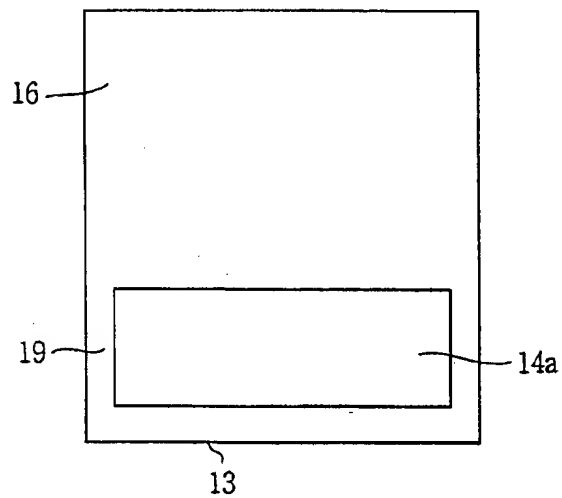


FIG.2

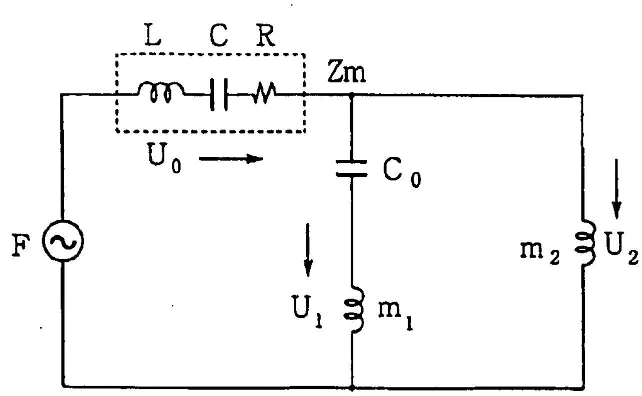


FIG.3

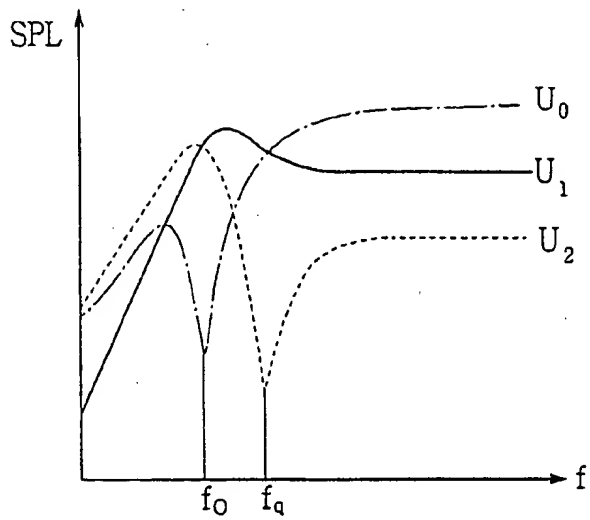


FIG.4

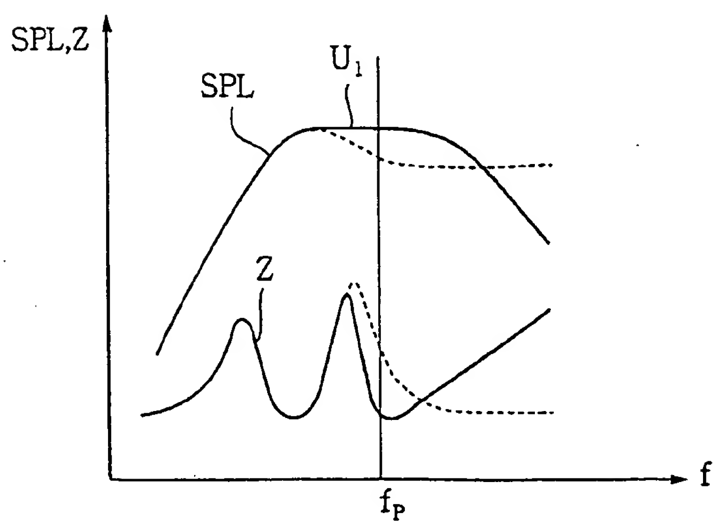


FIG.5

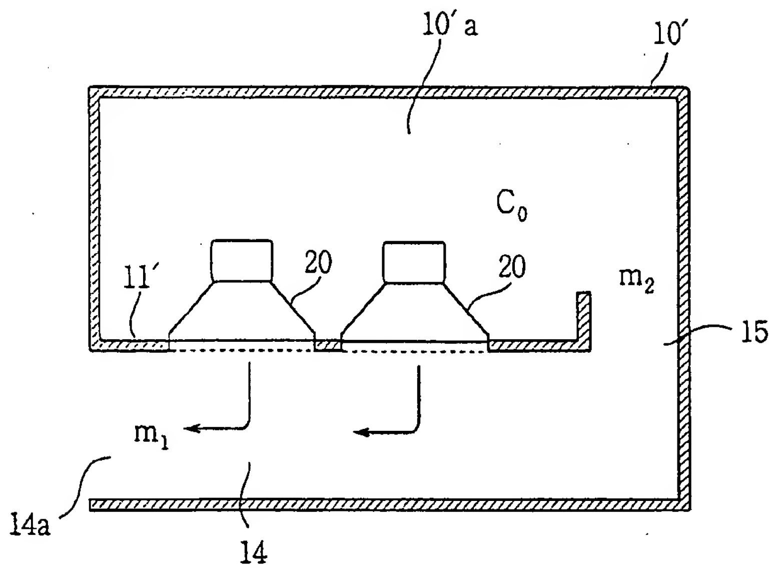


FIG.6

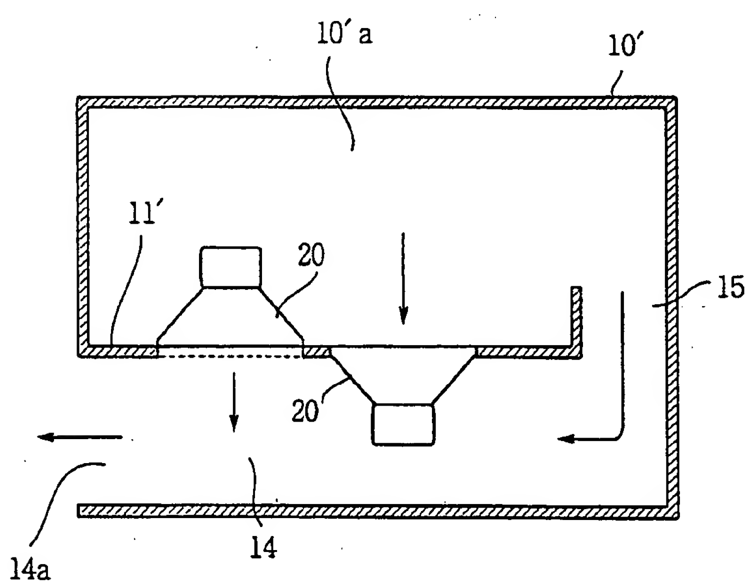


FIG.7

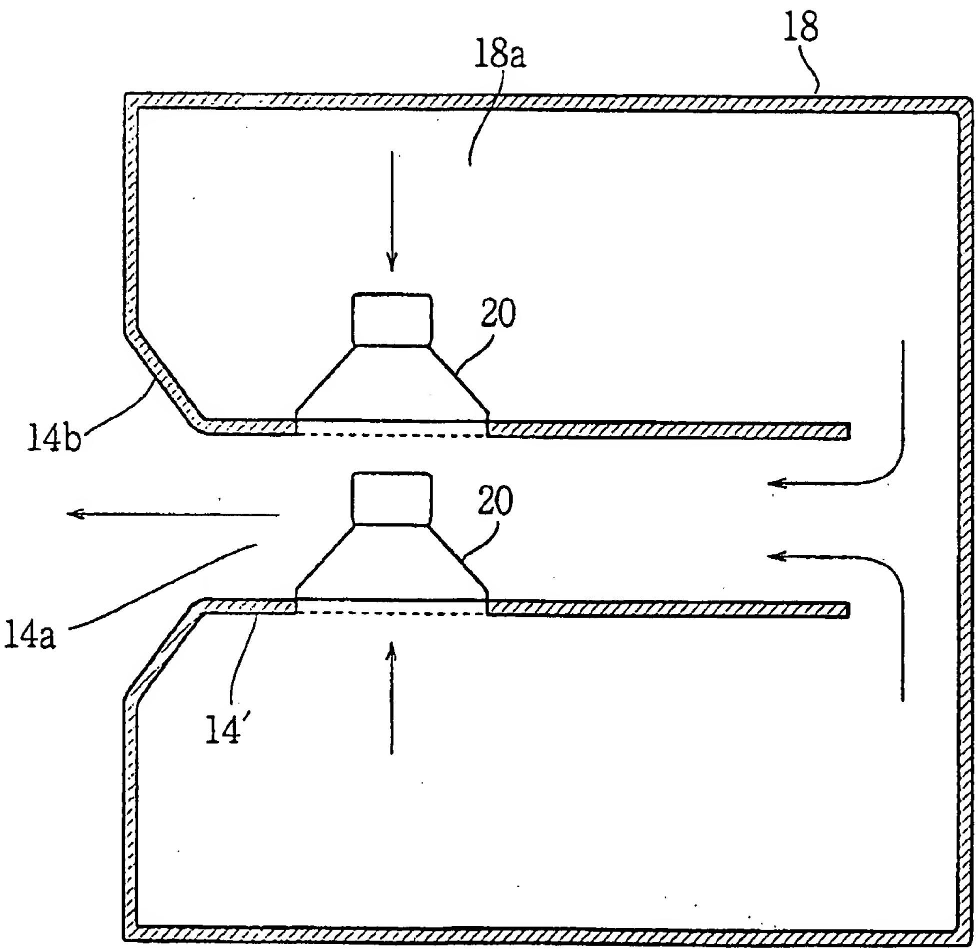


FIG.8

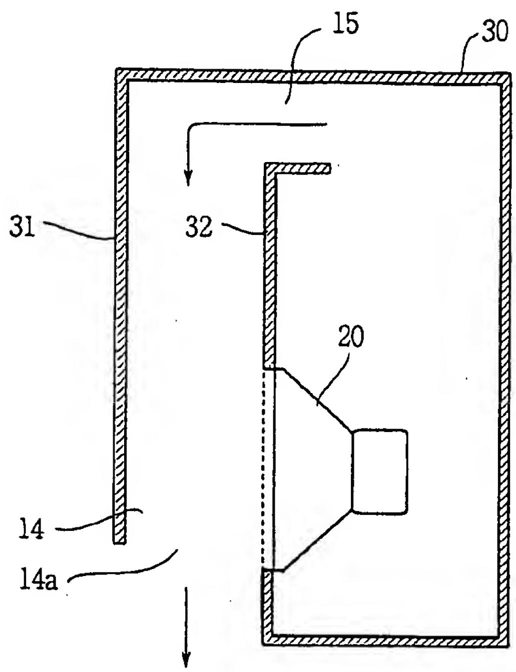


FIG.9

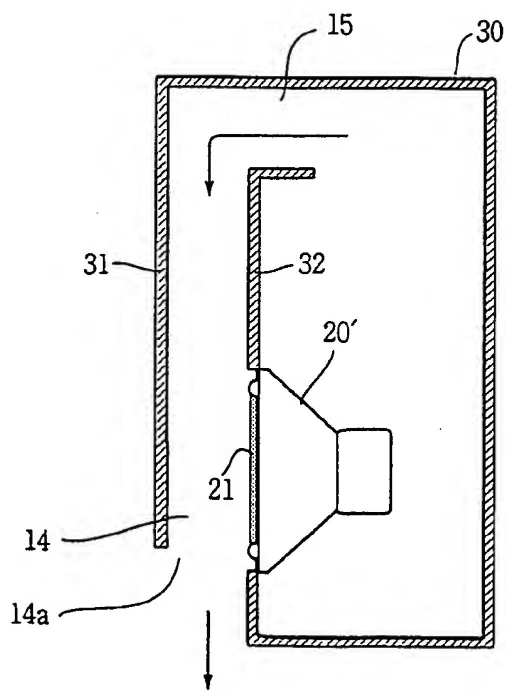


FIG.10

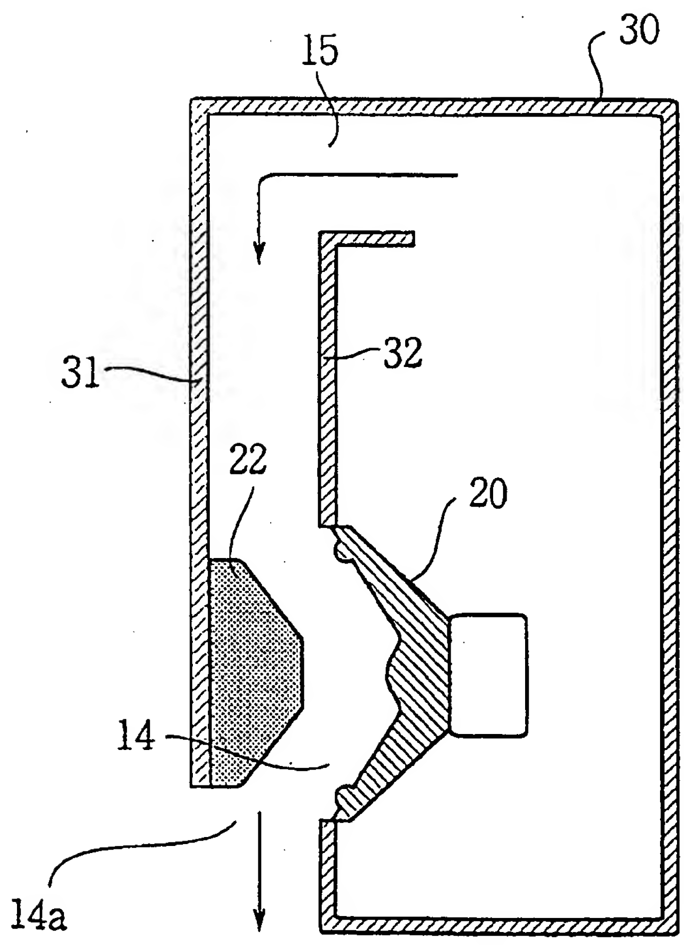


FIG.11

PRIOR ART

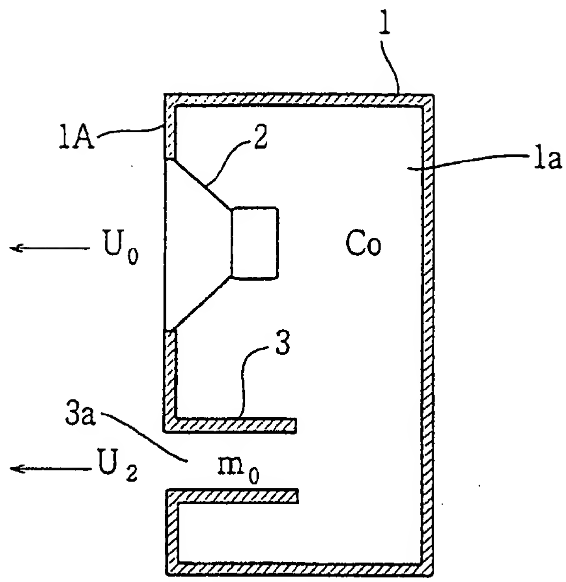


FIG.12

PRIOR ART

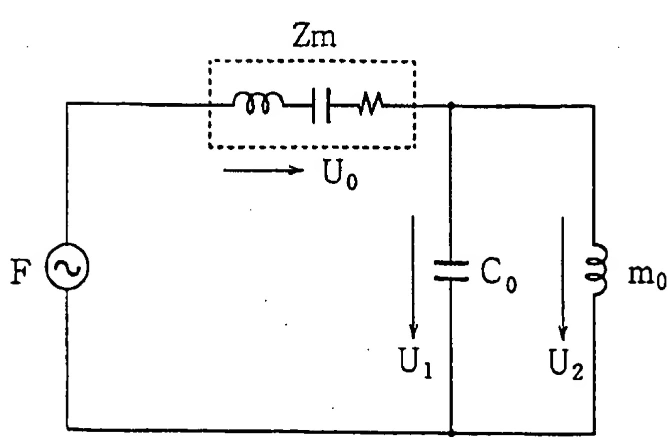


FIG.13

PRIOR ART

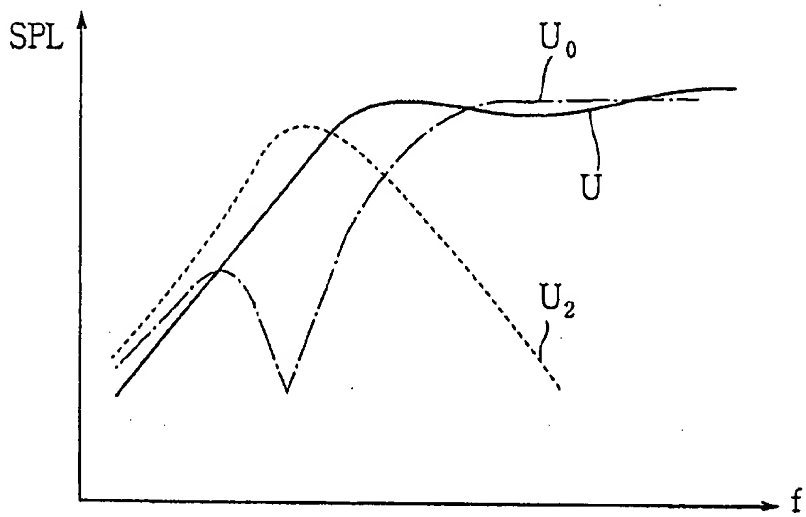


FIG.14

PRIOR ART

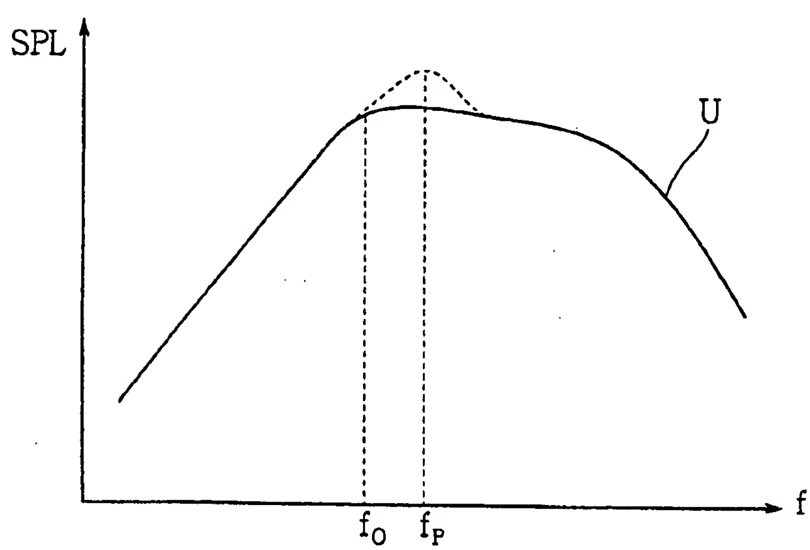


FIG.15

PRIOR ART

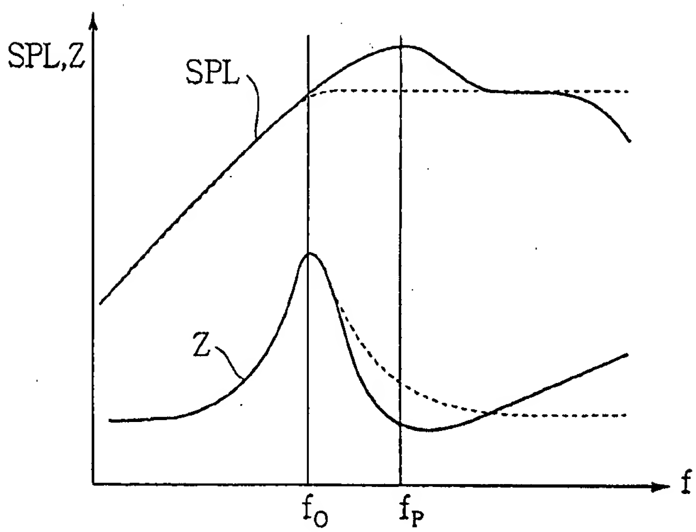


FIG.16

PRIOR ART

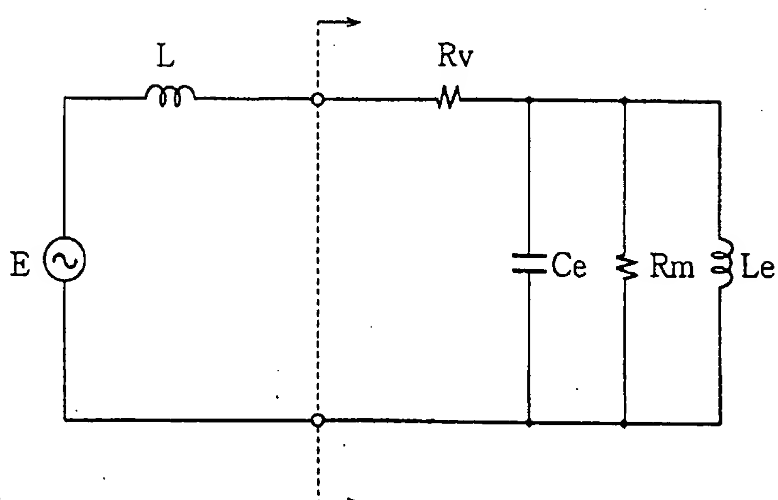


FIG.17

PRIOR ART

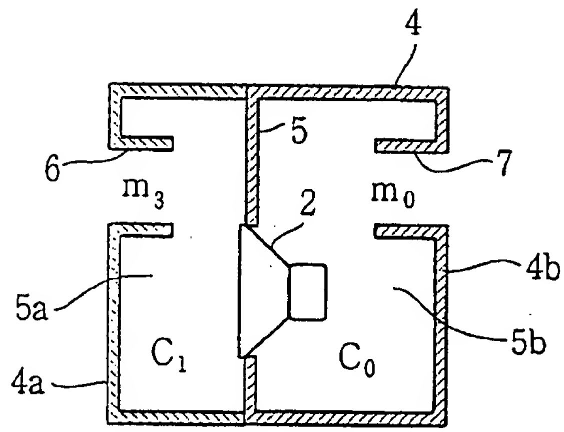


FIG.18

PRIOR ART

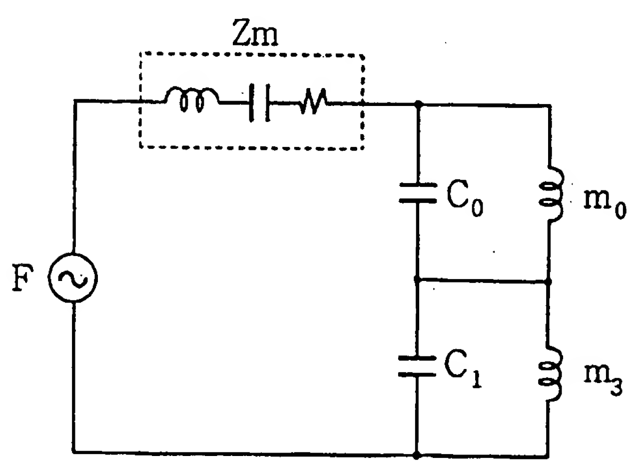


FIG.19

PRIOR ART

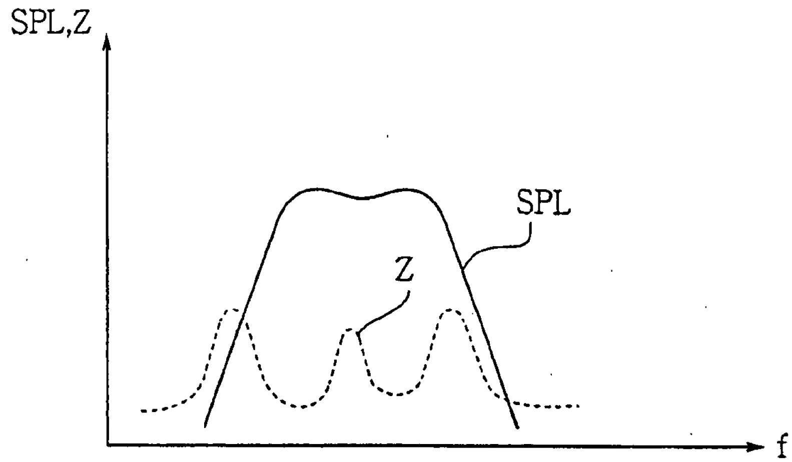


FIG.20

PRIOR ART

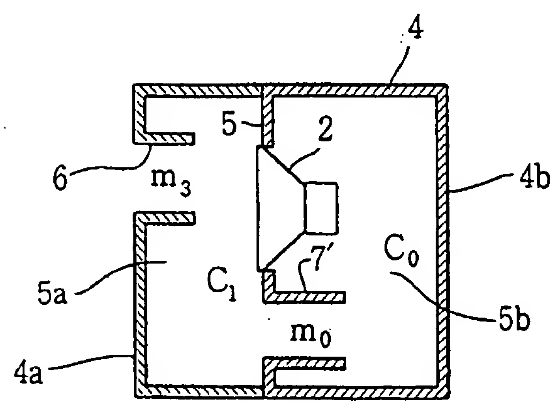


FIG. 21

PRIOR ART

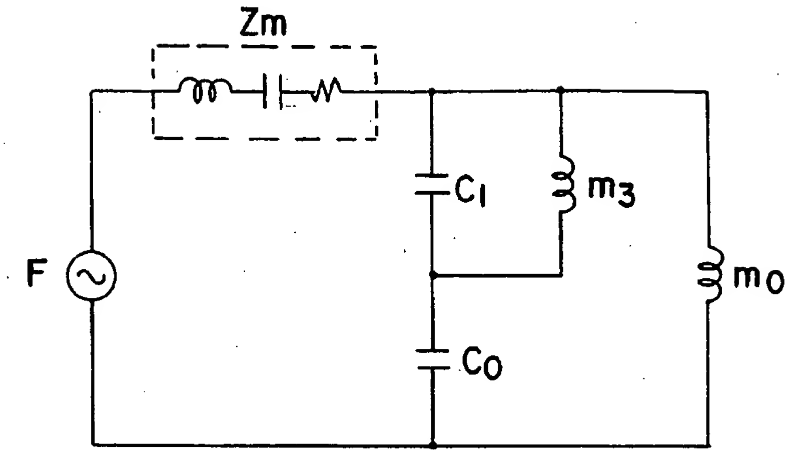
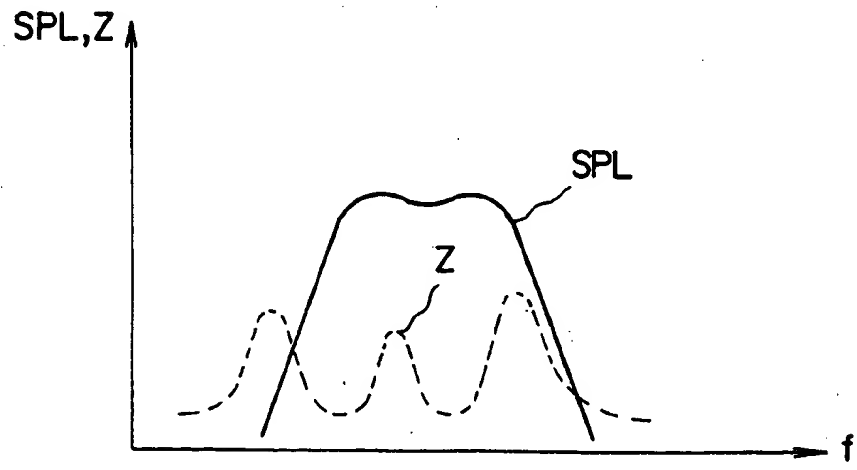


FIG. 22

PRIOR ART



SPEAKER SYSTEM

BACKGROUND OF THE INVENTION

The present invention relates to a speaker system having a bass-reflex cabinet.

In the speaker system, the formation of the cabinet affects the reproduction of low frequency sound. A bass-reflex cabinet is provided with a port formed in a front panel of a closed box. The sound rearwardly radiated in the cabinet is discharged from the port for increasing the low frequency characteristic.

FIG. **11** shows a conventional bass-reflex cabinet. A cabinet **1** comprises a speaker unit **2** secured to a front panel **1A** of the cabinet **1**. A bass-reflex duct **3** having a port **3***a* is provided on the front panel **1A** at a lower portion of the speaker unit.

When the speaker unit **2** emits sound, a part of the sound is radiated in the rearward direction in a cavity la of the cabinet **1** and enters the duct **3**. The sound is emitted from the port **3***a* and corrected into the same phase as the sound forwardly radiated from the speaker unit **2**. Thus, the low sound characteristic is increased.

The cavity **1***a* of the cabinet **1** has compliance **C0** and the duct **3** has mass **m0**.

A dividing network comprising a combination of a low-pass filter and a high-pass filter is used for deriving a frequency band corresponding to a particular speaker system. The dividing network is provided between an amplifier and the speaker system so as to divide an audio-frequency output of the amplifier into high, middle and low bands of frequencies. In order to increase the low frequency characteristic, the middle and high frequency bands are cut to extract the low frequency range which is applied to the bass-reflex cabinet.

However, the dividing network affects characteristics of sound pressure frequency, phase and impedance.

FIG. **12** shows a mechanical equivalent circuit of the speaker system. Mechanical impedance Zm of the speaker system is connected to the compliance **C0** of the cavity **1***a* and the mass **m0** of the duct **3** in series, respectively. The compliance **C0** and the mass **m0** are connected in parallel with each other.

When a driving force F is produced in accordance with an input signal from an amplifier thorough a dividing network, a diaphragm of the speaker unit **2** is vibrated to emit sound of volume velocity **U0**. The volume velocity **U0** is divided into volume velocity **U1** and volume velocity **U2** in dependency on the values of the compliance **CO** and the mass **m0**, respectively. The volume velocities **U0** and the **U2** are combined to the volume velocity **U1**.

FIG. **13** shows characteristics of sound pressures (SPL) which are obtained by converting the volume velocities **U0**, **U2** and U which is a combination of **U0** and **U2**. In the speaker unit, the dividing network is not provided.

FIG. **14** shows the combined sound pressure U when the dividing network is used. The dividing network operates to cut the high frequency range of the sound pressure U in accordance with a high-cut characteristic. Furthermore, the sound pressure is humped as shown by a dotted line at a frequency fp which is slightly higher than the lowest resonance frequency fo.

FIG. **15** shows the combined sound pressure U and an impedance characteristic Z. The dotted lines show the sound

pressure and impedance characteristics without the dividing network.

FIG. **16** shows an equivalent circuit for explaining why the sound pressure is humped when the dividing network is used. Inductance L of low-pass filter in the dividing network is connected to a capacitive component Ce in series to compose a series resonance circuit. Since the impedance is reduced at the frequency fp, flow of the current is increased.

Accordingly, in the speaker system with the dividing network, the sound pressure is humped at the frequency fp so that the sound pressure of the low frequency range is masked, thereby producing an oppressive sound in low frequency range.

In order to eliminate the disadvantage, a correction circuit is provided between the dividing network and the speaker system to correct the hump of the sound pressure. However, since the correction circuit is costly, manufacturing cost of the speaker system is increased.

FIG. **17** shows a bass-reflex cabinet of another conventional speaker system without using the dividing network. In the system, the high frequency range is cut in accordance with compliance in a cavity of the cabinet in front of the speaker unit.

A bass-reflex cabinet **4** has a central partition **5** to divide the cabinet **4** into a front cavity **5***a* and a rear cavity **5***b*. The speaker unit **2** is secured to the partition **5** facing on the front cavity **5***a*. The front cavity **5***a* has compliance **C1**, and a duct **6** having a mass **m3** is provided on a front panel **4***a* of the cabinet **4**. The rear cavity **5***b* has the compliance **C0**, and a duct **7** having the mass **m0** is provided on a rear panel **4***b* opposite to the duct **6**.

FIG. **18** shows an equivalent circuit and FIG. **19** shows a sound pressure characteristic SPL and an impedance characteristic Z of the system of FIG. **17**.

FIG. **20** shows a modification of the speaker system of FIG. **17**. The speaker unit **2** is secured to an upper portion of the partition **5** and a duct **7'** is provided on the partition **5** at a lower portion of the speaker unit **2** for communicating the rear cavity **5***b* with the front cavity **5***a*. The rear panel **4***b* has no duct. Other structures are the same as those of FIG. **17** and the same parts thereof are identified with the same reference numerals as FIG. **17**.

FIG. **21** shows an equivalent circuit and FIG. **22** shows a sound pressure characteristic SPL and an impedance characteristic Z.

In these speaker system, the compliance **C0** determined by the volume of the rear cavity **5***b* and the mass **m0** of the duct **7** affect the low frequency characteristic. If the values of compliance **C0** and mass **m0** are increased, the low frequency characteristic is increased.

The compliance **C1** determined by the volume of the front cavity **5***a* and the mass **m1** of the duct **6** cause an unnecessary high frequency range to attenuate. In order to increase the low frequency characteristic, it is necessary to increase the compliance **C0** and **C1**, causing the sizes (volumes) of the cavities **5***a* and **5***b* to be increased.

As shown in FIGS. **19** and **22**, each of the sound pressures has a double humped characteristic. Thus, it is possible to obtain a flat top characteristic at a necessary frequency range.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a speaker system where a low frequency characteristic is increased with a simple structure at a low cost.

According to the present invention, there is provided a speaker system having a cabinet, a speaker unit and a duct for radiating sound pressure emitted from the speaker unit, comprising the duct comprising a first duct extending in a direction perpendicular to a radiating direction of the sound pressure radiated from a front side of the speaker unit, and a second duct connected to an end of the first duct at one of ends thereof, and the other end of the second duct being communicated with in a space of the cabinet, the speaker unit being disposed at a connection of the first and second ducts.

The sound pressure radiated from a rear side of the speaker unit is propagated in the first duct and applied to the sound pressure from the front side of the speaker unit, and combined sound pressure is discharged from the first duct.

The other objects and features of this invention will become understood from the following description with reference to the accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1***a* is a sectional side view showing a cabinet of a speaker system according to the present invention;

FIG. **1***b* is a front view of the cabinet of FIG. **1***a*;

FIG. **2** is an equivalent circuit showing a mechanical system of the speaker system;

FIG. **3** is a graph showing sound pressure characteristics of the speaker system without a dividing network;

FIG. **4** is a graph showing sound pressure and impedance characteristics of the speaker system with the dividing network;

FIG. **5** is a sectional side view showing another embodiment of the present invention;

FIG. **6** is a sectional side view showing a modification of the embodiment of FIG. **5**;

FIG. **7** is a sectional side view showing another modification of FIG. **5**;

FIG. **8** is a sectional side view showing a further embodiment of the present invention;

FIG. **9** is a sectional side view showing a modification of the embodiment of FIG. **8**;

FIG. **10** is a sectional side view showing a modification of FIG. **9**;

FIG. **11** is a sectional side view showing a conventional speaker system;

FIG. **12** is an equivalent circuit showing a mechanical system of the conventional speaker system;

FIG. **13** is a graph showing sound pressure characteristics of the conventional speaker system without the dividing network;

FIG. **14** is a graph showing sound pressure characteristic of the conventional speaker system with the dividing network;

FIG. **15** is a graph showing sound pressure and impedance characteristics of the conventional speaker system with the dividing network;

FIG. **16** is an equivalent circuit showing an electric system of the conventional speaker system;

FIG. **17** is a sectional side view showing another conventional speaker system;

FIG. **18** is an equivalent circuit of FIG. **17**;

FIG. **19** is a graph showing sound pressure and impedance characteristics of the conventional speaker system of FIG. **17**;

FIG. **20** is a sectional side view showing a further conventional speaker system;

FIG. **21** is an equivalent circuit of FIG. **20**; and

FIG. **22** is a graph showing sound pressure and impedance characteristics of the conventional speaker system of FIG. **20**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. **1** showing a bass-reflex cabinet **10** of a speaker system according to the present invention, a front panel **16** of the cabinet **10** has a length which is shorter than a rear panel **17**. An inner base plate **11** is secured to the front panel **16** and opposite side plates **19**, and disposed in the cabinet to be parallel with a bottom panel **13** at a predetermined distance therebetween. An innermost end portion **11a** of the inner base plate **11** is disposed in the cabinet at a predetermined distance from the rear panel **17**. Thus, a horizontal duct is formed in the horizontal direction between the inner base **11** and the bottom panel **13**.

A speaker unit **20** is secured to a peripheral wall of an opening **12** formed in the inner base plate **11**. At the rear of the speaker unit **20**, a cavity **10***a* having the compliance **C0** is formed in the cabinet **10**. The horizontal duct is divided into a first duct **14** formed between the central axis of the speaker unit **20** and a port **14***a* of the duct, and a second duct **15** formed between the central axis of the speaker unit **20** and the innermost end portion **11***a* of the inner plate **11**. The second duct **15** is communicated with the cavity **10***a*. The first duct **14** has a mass **m1** and the second duct **15** has a mass **m2**.

When the speaker unit **20** emits sound, a part of the sound is radiated in the cavity **10***a* and enters the second duct **15** and added to the sound from the front of the speaker unit **20**. The confluent sound is discharged from the port **14***a* passing through the sound in the first duct **14**.

A sectional area of the first duct **14** is smaller than an area of a diaphragm (not shown) of the speaker unit **20**.

FIG. **2** shows a mechanical equivalent circuit of the speaker system. The circuit comprises a mechanical impedance Zm having L, C and R, and connected to the compliance **C0** of the cavity **10***a* and to the mass **m2** of the second duct **15**, respectively in series. The compliance **C0** is connected to the mass **m1** of the first duct **14** in series, and the compliance **C0** and the mass **m1** are connected in parallel with the mass **m2**.

In operation, when the driving force F is applied, the volume velocity **U0** is produced in accordance with the vibration of the diaphragm of the speaker unit **20**. The volume velocity **U0** is divided into the volume velocity **U1** of the first duct **14** and the volume velocity **U2** of the second duct **15** in dependency on the values of the compliance **C0** of the cavity **10***a* and the mass **m1** of the first duct **14**, and the mass **m2** of the second duct **15**, respectively. The volume velocities **U0** and **U2** are combined to the volume velocity **U1**.

Referring to FIG. **3**, the volume velocities **U0**, **U1** and **U2** are converted into characteristics of sound pressures without the dividing network. Since the sound pressure **U0** is produced in the forward direction and the sound pressure **U2** is produced in the rearward direction corresponding to the diaphragm of the speaker unit **20**, the sound pressures **U0** and **U2** have a reverse phase. Thus, the sound pressure **U1** is obtained by combining the sound pressures **U0** and **U2**,

namely by subtracting the sound pressure U2 from the sound pressure U0.

The combined sound pressure U2 is humped at the frequency fo and reduced in a higher frequency range than the frequency fo. Such a sound characteristic is caused by the sound pressure U2 of the second duct **15**. As shown in FIG. **2**, the mass m1 of the first duct **14** is connected to the compliance C0 of the cavity **10***a* in series to form a series resonance circuit. Thus, the sound pressure U0 is increased at a resonance frequency of the circuit, thereby reducing the sound pressure U2 so that the sound pressure U2 is radically dipped at the resonance frequency which is higher than the resonance frequency fo and increased in a higher frequency range than the former resonance frequency. Thus, the sound pressure U2 affects the sound pressure U1 which is reduced at the high frequency range.

The sound pressure U2 is not reduced at the high frequency range due to the impedance remained in accordance with the mass m1, and has asymptotic characteristic to a predetermined value determined by a proportion to the masses m1 and m2. Thus, the combined sound pressure U1 becomes a constant value smaller than the sound pressure U0.

Referring to FIG. **4**, when the dividing network is used, the combined sound pressure U1 is humped so as to approximate a sound pressure at the frequency fo. Thus, the hump of the sound pressure U1 is disappeared. Consequently, the sound pressure U1 has a flat top characteristic.

If the sound pressure is humped at the frequency slightly higher than the frequency where the sound pressure is dipped, the sound pressure is humped continuously with the highest sound pressure at the frequency fo. Thus, the flat top characteristic is further increased.

In the system, the lowest frequency for reproducing the low frequency range is lowered compared with the conventional system. The lowest frequency for reproducing the low frequency range is the frequency fr where the sound pressure U0 is radically dipped.

The frequency fr is determined in accordance with the compliance C0 of the cavity **10***a* and the sum of the masses m1 and m2 of the first and second ducts **14** and **15** (m1+M2) and represented by an equation as follows.

$$fr \cong \frac{1}{2\pi}\sqrt{(1/(m1+m2)C0)}\ (HZ) \ldots \quad (A)$$

In the conventional speaker system shown in FIG. **17** or FIG. **20**, the frequency fr is represented as

$$fr \cong \frac{1}{2\pi}\sqrt{(1/(m0 \cdot C0))}\ (HZ) \ldots \quad (B)$$

From the foregoing, it will be seen that if the volume of the cabinet of the present invention is the same as that of the conventional cabinet, the compliance C0 of the present invention is larger than that of the conventional system. Thus, it is possible to lower the frequency. In other word, the cabinet having a smaller volume can achieve the lowest frequency for reproducing the low frequency range to a predetermined low value.

The relationship between sectional areas of the first and second ducts **14** and **15** affect the sound pressure characteristic.

The sound pressure characteristic can be changed by changing the sectional area of the first duct or the second duct, if the size of the cabinet is limited, as described below. If the first duct **14** has a length L1 and the second duct **15** has a length L2, and both lengths are constant, the sound pressure characteristic is determined as follows.

If the sectional area of the first duct is larger than that of the second duct, a reproducible frequency of a low frequency range is increased as well as a middle frequency range, compared with a case where both the sectional areas are equal to each other. If the sectional area of the first duct is smaller than that of the second duct, the reproducible frequency of the low frequency range is reduced as well as the middle frequency range.

In the embodiment, since the dividing network is used, the sound pressure is humped due to the resonance. The hump is corrected to flat the sound pressure characteristic. Thus, the problem such as masking in the low frequency range is solved, the characteristic of low frequency is improved.

In the cabinet of the speaker system, a plurality of speaker units may be provided on the inner base plate **11**.

FIG. **5** shows another embodiment of the speaker system of the present invention. In the system, the second unit **15** is provided perpendicular to the first duct **14**. In a bass-reflex cabinet **10'**, a pair of speaker units **20** are secured to an inner base plate **11'** along the axis of the first duct **14**. In such a system, the sound source is distributed in the first duct **14**, thereby reducing a peak dip of the sound pressure in accordance with resonance of the duct caused by the length of the duct.

FIG. **6** shows a modification of the system of FIG. **5** where a pair of speaker units **20** are secured to the inner base plate **11'**,in the opposite directions. In the system, if a push-pull operation is used to reverse polarities of input signals of speaker units **20**, even order harmonic distortion of the speaker unit is canceled so that harmonic distortion of the sound pressure is remarkably reduced.

FIG. **7** shows a further embodiment of the present invention. A horizontal duct **14'** is provided in a central portion of a bass-reflex cabinet **18** and pair of speaker units **20** are secured to opposite portions of the duct **14'** in the same direction. A tapered portion **14***b* is formed on the port **14***a* of the duct **14'**. A cavity **18***a* is formed around the duct **14'**.

Abnormal noises caused by a large output power is reduced in the system. By using the push-pull operation, distortion is reduced to obtain a high quality sound.

Furthermore, the shape of the first duct is changeable if the shape is regarded as a duct.

Referring to FIG. **8**, a bass-reflex cabinet **30** has a vertical inner front plate **32** to which the speaker unit **20** is secured. A front panel **31** of the cabinet **30** has such a length that the lower edge of the panel **31** does not reach the bottom of the cabinet. Thus, a part of the speaker unit **20** is exposed from the front panel **31**. The first duct **14** is formed in front of the speaker unit.

Referring to FIG. **9**, the first duct **14** has a small sectional area compared with that of the duct of FIG. **8**. Thus, a speaker unit **20'** having a flat diaphragm **21** is secured to the inner base plate **32**.

FIG. **10** shows a modification of FIG. **9** where an equalizer **22** is secured to an inner portion of the front panel **31** in the first duct **14** corresponding to an indentation of the speaker unit **20**. Thus, a constant sectional area of the first duct **14** is obtained.

In the cabinet, if the distance between the front panel **31** and the inner plate **32** is reduced so that the sectional area of the first duct **14** is small, the speaker unit **20** is closed to the front panel. Particularly, in the above-mentioned type of the cabinet, if the sectional area of the duct changes in accordance with the shape of the diaphragm of the speaker unit, the system is not normally operated. Therefore, it is difficult to obtain a flat top characteristic of the sound pressure.

In accordance with the present invention, the bass-reflex cabinet has first and second ducts to combine sound pres-

sures radiated in the forward and rearward directions of the speaker unit in the cabinet.

The lowest resonance frequency is lowered to reduce unnecessary sound pressures in the middle and high frequency ranges. Thus, in the cabinet having a small size, the reproducing band can be extended to a lower frequency range.

When the dividing network is provided, the sound pressure is liable to be humped due to the resonance. In the present invention, the flat top characteristic can be obtained by using the hump of the sound pressure. Thus, reproduced sound of high quality and good feeling of expansion in auditory sensation can be provided.

While the presently preferred embodiments of the present invention has been shown and described, it is to be understood that these disclosures are for the purpose of illustration and that various changes and modifications may be made without departing from the scope of the invention as set forth in the appended claims.

What is claimed is:

1. A speaker system comprising:

a cabinet;

a first speaker unit provided within the cabinet; and

a duct for radiating sound pressure emitted from the first speaker unit,

wherein a drive signal to be applied to the speaker unit is passed through a network circuit means, said network circuit means for eliminating a high frequency component contained in the drive signal,

wherein the duct extends in a direction perpendicular to a radiating direction of the sound pressure radiated from a front side of the first speaker unit, with one end of the duct being communicated with a space of the cabinet, and another end of the duct forming an opening of the speaker system;

wherein the first speaker unit is disposed with the front side thereof positioned at a portion of a wall of the duct;

wherein the duct has a cross section which is perpendicular to a sound propagating direction and has a consistent cross sectional area along an entire length thereof; and

wherein sound pressure radiated from a rear side of the first speaker unit is propagated in the duct and applied to the sound pressure from the front side of the first speaker unit, and combined sound pressure is discharged outwardly from the duct.

2. The speaker system according to claim **1** wherein a second speaker unit is provided on the wall of the duct.

3. The speaker system according to claim **2**, wherein the first and second speaker units are disposed in opposite directions.

4. The speaker system according to claim **1** wherein the duct is disposed in a central portion of the cabinet.

5. The speaker system according to claim **1** wherein the duct is horizontal.

6. The speaker system according to claim **1** wherein the duct is vertical.

* * * * *